Batteries and Energy Storage: The Next Technology Advances

Multi-Client Study Proposal

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TCGR THE CATALYST GROUP RESOURCES™

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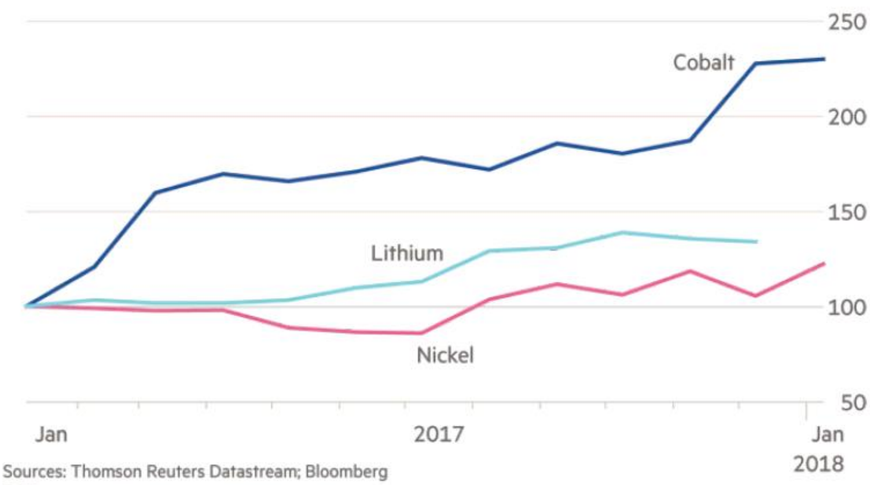
According to Jeff Chamerlian who heads the Volta Technologies fund, backed by Albemarle, and U.S. utility Exelon, “the innovation pipeline is so full right now it’s actually chaotic!” The fund’s ambition is to fund those companies whose battery technologies will triumph in the global battle to dominate electric cars and energy storage. The global supply is expected to more than double by 2020. While lithium-ion batteries will remain in electric cars into the foreseeable future, there is a host of innovations and promising new materials that can be used to improve that technology (Financial Times, 1/11/2018, p. 18).

Commodities

Prices rebased



Sources: Thomson Reuters Datastream; Bloomberg
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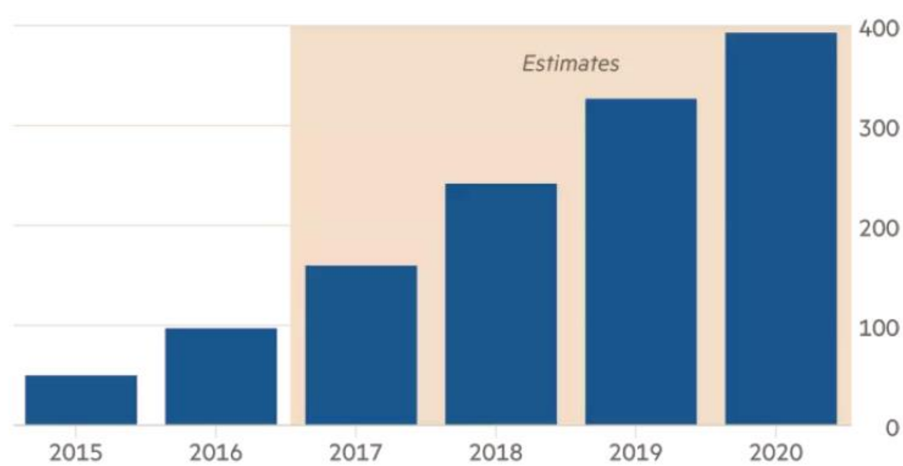
Global EV/energy storage systems battery supply

Gigawatt hours



Source: Bernstein
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I. INTRODUCTION

Improvements in lithium-ion secondary battery technology remain minor and incremental, whereas the anticipated complete electrification of the transportation infrastructure and a full transition to renewable energy sources for power generation will require a transformational energy storage solution. To understand these changes, there is a need to address and categorize materials science related energy storage advances, including existing lithium-ion technology and research efforts, and analyze how these efforts affect electric vehicle and renewable energy power generation adoption. Just as critical is a review of the resulting imminent and extremely rapid acceleration of production capacity of related materials for existing battery formats and chemistries required in the next five years to meet these demands. Beyond this short term discussion is the key issue of advancing existing Li-ion chemistry to its theoretical limits as a medium-term discussion, and analyzing the possibilities of what energy storage technology will replace Li-ion by 2030 and the materials science advances required to do so.

TCGR's proposed study, entitled "***Batteries and Energy Storage: The Next Technology Advances***," will use a commercial and technical literature analysis, including patent and research paper analysis, to highlight important commercial and research development paths for both lithium-ion and near-term and future battery chemistries. This technical review will be combined with an end-market assessment of mobile and stationary energy storage/battery demand to understand production requirements and raw material needs in the context of the highly accelerated demand expected for these batteries over the next decade.

II. BACKGROUND

The shift to electric vehicles from traditional internal combustion engines is accelerating, with policies providing impetus for the change. Already, the UK and France have declared that gasoline and diesel vehicles will no longer be sold in these countries by 2040, and China is considering a similar announcement. However, low battery density and inadequate storage capacity are considerable barriers preventing wider adoption of electric vehicles.

On the stationary side, the importance of coal and natural gas for power generation is receding, replaced by wind and solar power to such an extent that renewable energy sources are now providing the majority of new energy capacity installed each year. With this rapid (and to many, inevitable) transition to renewable energy, the intermittent nature of wind and solar means a tremendous number of energy storage systems (ESS) are needed for these renewable energy sources to operate as baseline power generation within the grid and completely transplant fossil fuels.

Lithium ion (Li-ion) has become the battery chemistry of choice for virtually all mobile and stationary applications, but improvements in the energy capacity of the current generation of Li-ion batteries are only incremental. A study by the International Renewable Energy Agency (IRENA) shows that while the organization expects installation costs and calendar life for stationary ESS to improve between now and 2030, there will be no substantial improvement in energy density and round-trip (i.e., charging) efficiency in that same timeframe.

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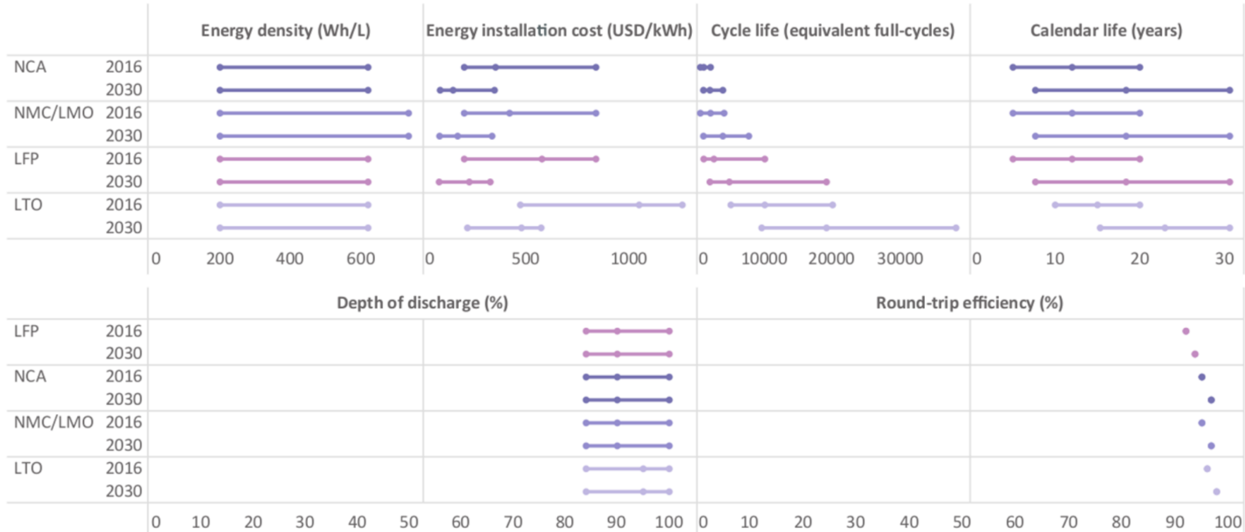
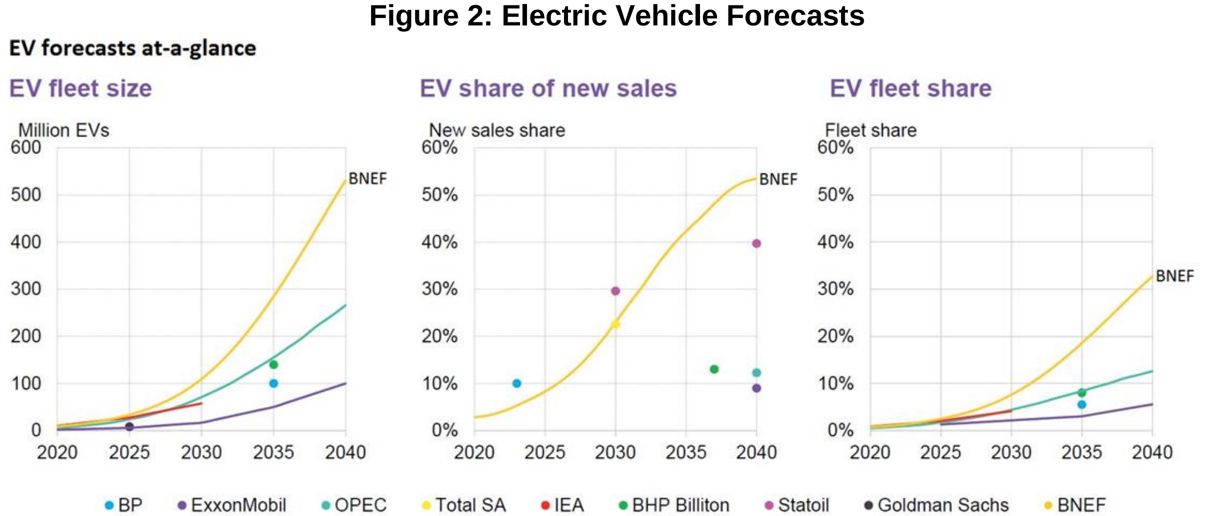
Figure 1: Properties of selected chemistries of lithium-ion battery electricity storage systems, 2016 and 2030



Source: IRENA 2017

While the gains to lithium-ion's capabilities are limited despite extensive research, development of infrastructure to produce batteries for mobile and stationary applications is incredible and continues to grow at a rate much faster than production capacity for lithium-ion batteries destined for the electronics and communications markets. An analysis by Bloomberg New Energy Finance (BNEF) has global (non-hydro) stationary energy storage rising almost exponentially between 2016 and 2030 to 305 GWh, while the International Renewable Energy Agency (IRENA) forecasts 2030 stationary storage to be between 167 GWh and 421 GWH. Electric vehicle penetration will be just as abrupt, with forecasts ranging anywhere from 10% to 40% of new vehicle sales worldwide by 2030, which is a very wide range.

Figure 2: Electric Vehicle Forecasts



Source: Bloomberg New Energy Finance, organization websites

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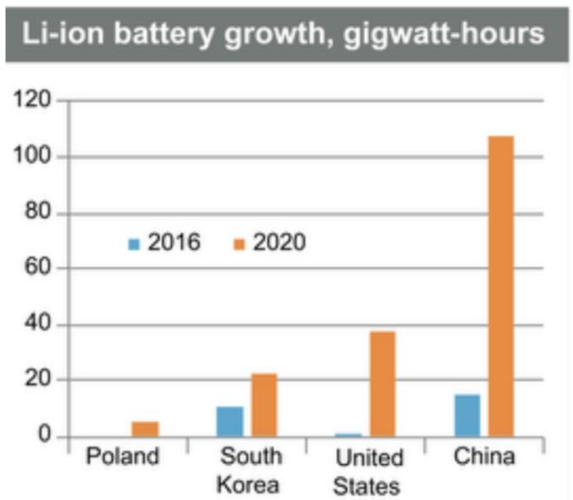
These changes require a massive amount of Li-ion batteries, far more than current global production capacity can provide. Tesla, TerraE Holding, and others are building so-called gigafactories capable of over 1 GWh of Li-ion battery production per year to meet the anticipated growth in mobile and stationary energy applications, and global production is expected to increase five-fold to over 100 GWh per year by 2020.

In parallel but related activities, traditional vehicle exhaust catalyst manufacturers Johnson Matthey and BASF are also investing hundreds of millions of dollars to develop the production infrastructure needed to pivot away from environmental catalysts—which are not be needed for EVs—to batteries. However, a question remains as to how much of this new Li-ion battery production infrastructure will itself become obsolete as new energy storage technologies come into play.

Figure 3. Li-ion Battery Production (GWh), 2016 and 2020



Source: Ravenscroft 2017 (citing Benchmark Mineral Intelligence)

Researchers and market participants are taking many approaches to reduce costs and improve the characteristics of Li-ion batteries. As one example, SK Innovation will be starting production of medium and large NCM-811 batteries (80% Ni, 10% Co, 10% M) in 2018 that are cheaper to produce than standard **NCM** batteries and can provide more range to EV vehicles. Toshiba will start producing a new generation of its **SCiB** batteries based on a titanium niobium oxide anode that supports ultra-fast charging such that 300 km driving range could be provided in a 32 kWh battery pack in six minutes.

Silicon anodes have a theoretical gravimetric capacity 10 times higher than graphite, and the chemistry is just starting to appear in commercial production of batteries for EVs, such as Enevate Corp's HD-Energy battery with a 70% silicon anode. **Lithium anode** batteries are another next-generation battery chemistry and a similar state of development, with Sion Power introducing its Licerion battery with double the specific energy of existing chemistries with a carbon anode for mobile applications in 2018.

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Lithium-sulfur (Li-S) batteries are a potential long-term successor to Li-ion, possessing a higher theoretical specific energy, specific energy capacity, and volumetric capacity while also combining a more abundant and cheaper material than lithium. Other potential battery chemistries such as **magnesium-ion** or **sodium-ion** move completely away from lithium. Magnesium has a theoretical volumetric energy density almost twice as high as Li^+, but needs development of an electrolyte that enables a reversible reaction. Sodium-ion batteries have the potential to rival lithium-ion for battery characteristics at a fraction of the price, but researchers of sodium-ion batteries still need to find a better anode than hard carbon to improve long-term cycle life.

III. THE NEED FOR THE STUDY

While there is a clear understanding that Li-ion battery production will grow tremendously over the next decade, it is decidedly less clear as to what technology developments are necessary to achieve that growth and how new technology changes will affect production and costs. **This report will be unique in that it will look at both current lithium-ion technology advancements and the potential new materials science and chemistries that will replace Li-ion from the perspective of theoretical achievements against the required material and production costs required to achieve those gains. A number of key issues will be addressed in the report, including the potential production bottlenecks for Li-Ion batteries over the next five to ten years as production capacity accelerates, and determination of the research pathways that show the most promise for economically improving mobile and stationary battery chemistries.** Other important areas to be addressed are:

- Recent patent activity for Li-ion batteries
- Research into near-term improvements to Li-ion chemistries
- Outline and compare mid-term battery technologies that can move beyond Li-ion
- Long-term battery and energy storage technologies that will be needed post 2030 to sustain a transportation infrastructure that is almost fully electric and a power generation framework where the majority of energy comes from renewable energy sources and supported with grid storage.

IV. SCOPE AND METHODOLOGY

This study will analyze the functional materials and different chemistries making up today's Li-ion batteries used for mobile and stationary applications through:

- Detailing current battery use in EVs and stationary energy storage solutions
- The research paths being studied to improve material and battery characteristics for all components of the battery
- Economic investments and costs
- Current development paths companies are pursuing to push the Li-ion chemistry closer to its theoretical maximum in terms of energy density and to improve cycle life

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- Compare the characteristics of various Li-ion chemistries available today (LCO, NMC, LCA, etc.)
    - Capacity, density, material costs, cycle life, etc.
- Report chemistry improvement potential based on current research efforts on these paths

However, Li-on is only the acceptable battery choice for the current generation of mobile and stationary applications, so this report further looks into the commercialization paths of both near-term and long-term energy storage/battery material science/chemistries that can potentially replace lithium-ion. Topics will include:

- Alternative lithium-based battery chemistries (lithium metal anode, Li-S, etc.)
    - Developers, state of production (if any)
- Metal-air batteries
- Comparison of potential costs for different future battery technologies
    - Materials, production costs, ease of retrofitting existing Li-ion production capacity

The study will combine a data-driven technical/commercial literature and patent review with detailed technological assessments as determined by the industry's leading participants as "charter" subscribers. This detailed assessment of current and future mobile and stationary battery technologies will be augmented with economic analyses of material and production components related to these technologies, as battery production capacity remains a major issue over the next decade.

TCGR will use in-house and external resources, as well as expertise from within industry as well as our highly regarded DIALOG GROUP ® in order to complete:

– Technology evaluations
– Patent reviews and analyses
– Representative economics
– Market size/growth and needs/drivers
– Competitive implications (developers vs. users)

A proposed/preliminary Table of Contents is provided on page 7 in order to depict the breadth and depth of the study as envisioned.

References

Financial Times, *Volta Energy joins the fray in battle for battery technologies,* January 11, 2018, p. 18.

IRENA (International Renewable Energy Agency); *Electricity Storage and Renewables: Costs and Markets to 2030*; Abu Dhabi; 2017.

Ravenscroft M.; *Lithium-ion batteries generate growth*; Chemical Week, 23/30 Oct., 2017.

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Preliminary Table of Contents*
Batteries and Energy Storage: The Next Technology Advances

**Charter subscribers (those who sign up for the study before March 9, 2018) will have the opportunity to work with TCGR to further refine the scope of the report by delineating areas of particular interest for inclusion in the assessment.*

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V. QUALIFICATIONS

The Catalyst Group Resources, a member of The Catalyst Group, works with clients to develop sustainable competitive advantage in technology-driven industries such as chemicals, refining, petrochemicals, polymers, specialty/fine chemicals, biotechnology, pharmaceuticals, and environmental protection. We provide concrete proven solutions based on our understanding of how technology impacts business.

Using our in-depth knowledge of molecular structures, process systems, and commercial applications, we offer a unique combination of business solutions and technology skills through a range of client-focused services. Often working as a member of our clients' planning teams, we combine our knowledge of cutting-edge technology with commercial expertise to:

- Define the business and commercial impacts of leading-edge technologies
- Develop technology strategies that support business objectives.
- Assess technology options through strategy development, including:
  - Independent appraisals and valuations of technology/potential
  - Acquisition consulting, planning and due diligence
- Provide leading-edge financial methodology for shareholder value creation
- Lead and/or manage client-sponsored R&D programs targeted through our opportunity identification process.
- Provide leading information and knowledge through:
  - World-class seminars, conferences and courses
  - Timely technical publications

The client-confidential assignments conducted by The Catalyst Group include projects in:

- Reinventing R&D pipelines
- Technology alliances
- Technology acquisition
- Market strategy

We have built our consulting practice on long-term client relationships, dedication, and integrity. Our philosophy is clear and focused:

We Provide the "Catalysts" for Business Growth by Linking Technology and Leading-Edge Business Practices to Market Opportunities

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VI. DELIVERABLES AND PRICING

This report is timely and strategically important to those industry participants and observers both monitoring and investing in the development and implementation of technologies for energy storage and/or battery materials. TCGR's report, based on technology evaluations, commercial/ market assessments and interviews with key players will go beyond public domain information. As a result, subscribers are requested to complete and sign the "Order Form and Secrecy Agreement" on the following page.

The study, **"Batteries and Energy Storage: The Next Technology Advances"** is expected to be available in June/July, 2018.

Participation	Deadline	Price
"Charter" subscribers*	before March 9, 2018	$17,500
Batteries and Energy Storage: The Next Technology Advances		
Post-launch subscribers	after March 9, 2018	$20,500
Batteries and Energy Storage: The Next Technology Advances		
Report in PDF format, in addition to subscription price		$1,000

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Please enter our order for **"Batteries and Energy Storage: The Next Technology Advances,"** to be completed in June/July, 2018, as follows:

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